DER Interconnection Systems Technology Review

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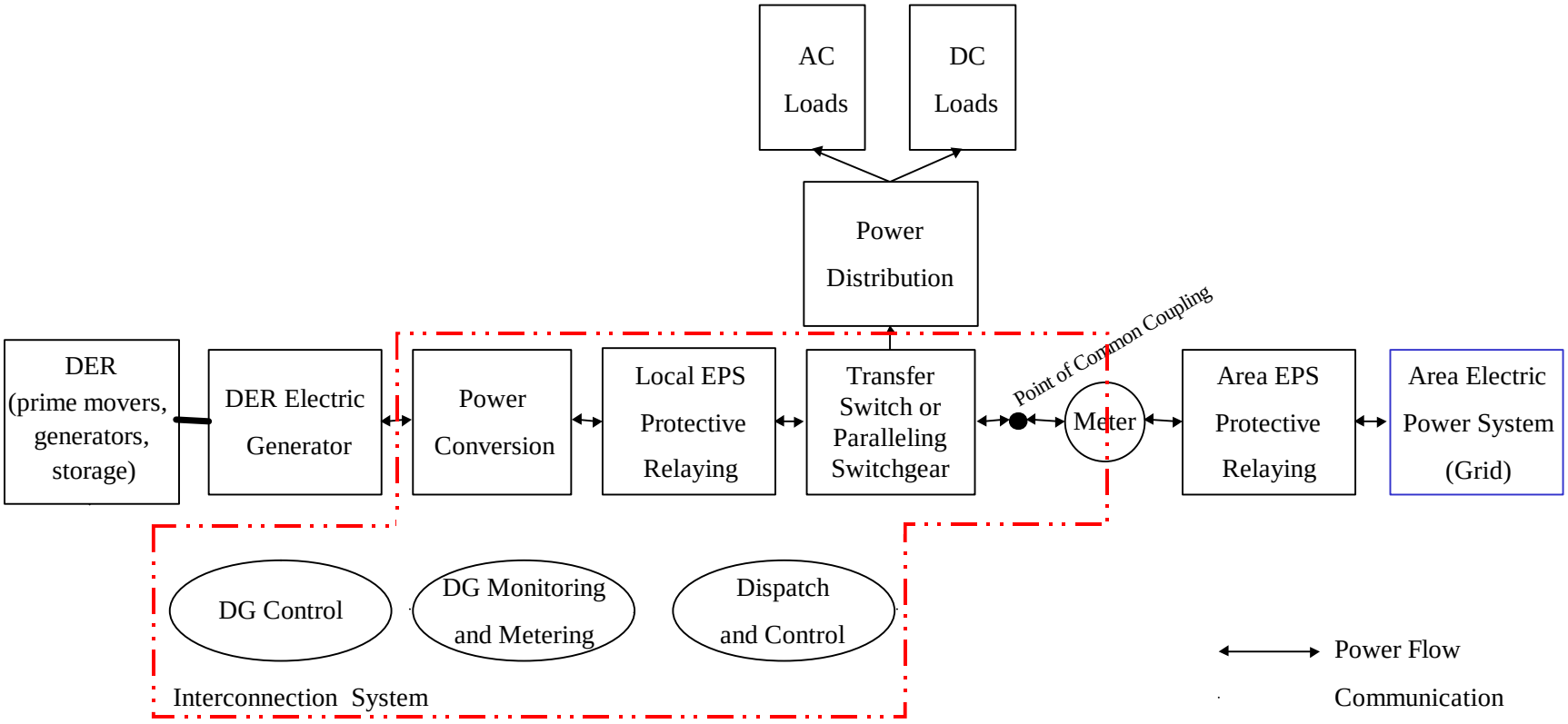
The Interconnection System

- Equipment comprising the electrical connection between the DER and the grid
- Also provides one or more of the following:
  - local and/or remote monitoring
  - local and/or remote control
  - metering
  - local and/or remote dispatch of the DER unit

Interconnection System Complexity

- Depends on the level of interaction required between the
  - DER
  - customer loads
  - Area EPS
- DER units can be interconnected with the following operating modes:
  - Isolated DER operation/automatic transfer between the DER and the Area EPS
  - Parallel operation with Area EPS/no power export
  - Parallel operation with Area EPS/power export

The Interconnection System



DER Interconnection Standardization

- Current approach
  - various engineering designs
  - collection of individual components
- Promised benefits from
  - standardization
  - integration
  - interoperability
- Area EPS practices dominate interconnection considerations today

DER Interconnection Technology Development at a Crossroads

- Digital, multi-function relays emerging
- Rise of inverter technology opened door to inverter-based protective relaying
- Utility protection and coordination practices based on “discrete” relays on utility side of meter
- Utility protection engineers now learning and becoming familiar with digital circuitry

Report Objectives

- Describe interconnection configurations
- Identify manufacturers and suppliers of interconnection equipment
- Characterize current interconnection product offerings and capabilities
- Assess interconnection codes & standards (current and planned)
- Review interconnection costs and RD&D needs
- Strategy for responding to the needs
- Next steps

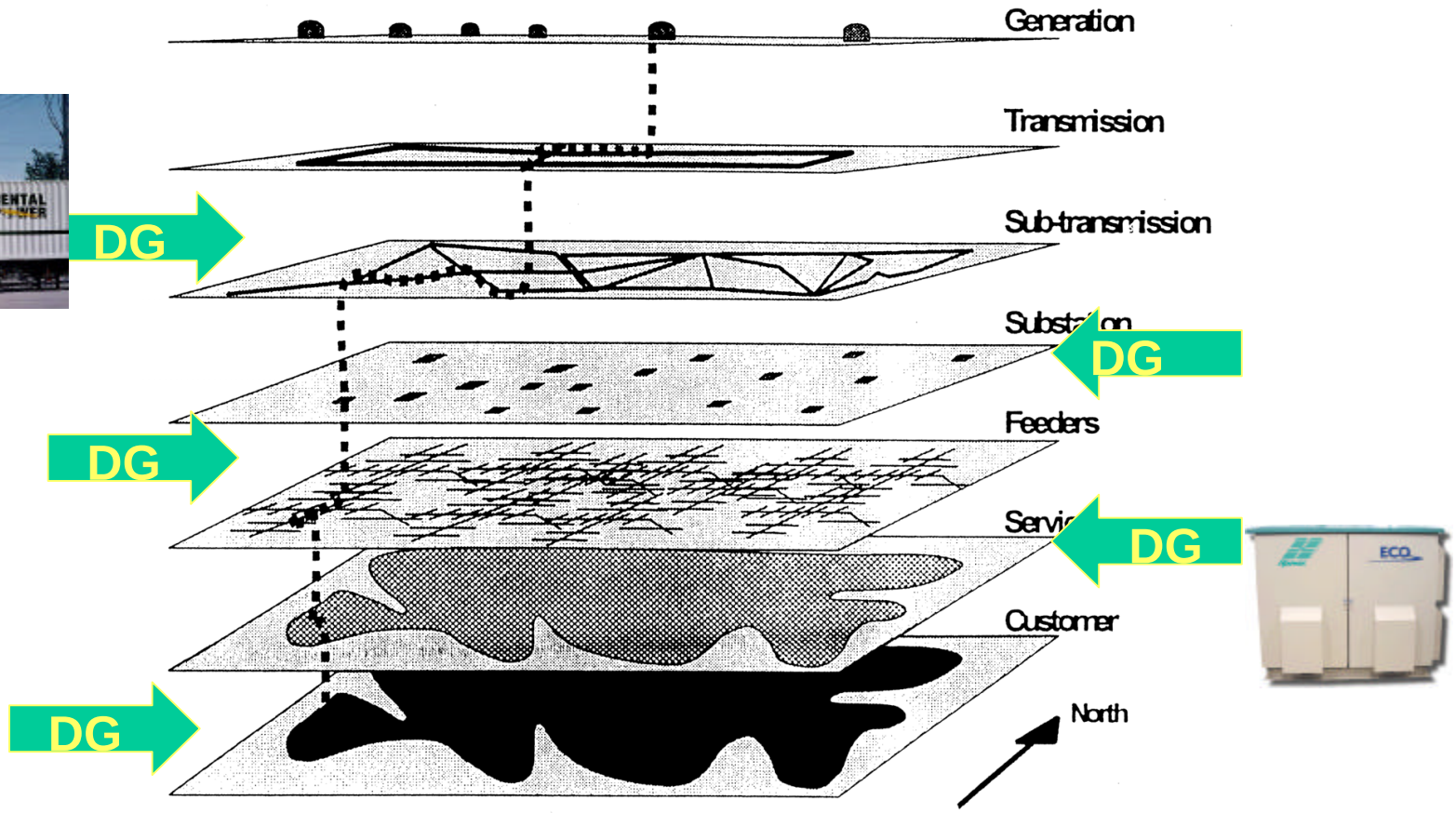
Study Approach

- Build on results of July 2001 DOE/NREL Systems Integration Technology Workshop
- Research and interviews with equipment manufacturers
- Develop extensive “catalogue” of commercially-available products and costs
- Establish foundation for functionality needs of next generation interconnection package and the “universal interconnection technology”

Focus of the July 2001 Workshop

- Balance between cost and functionality in each component of the interconnection system?
- What should the interface standards be between DER and the interconnection package, and should such standards be universal in a move toward plug-and-play capability?
- Should interconnection controls, meters, and monitoring functions be included as part of the genset, or located in a separate interconnection package?
- What is the preferred approach – a single integrated interconnection package or an assembly of subsets that can be engineered and combined at the DER site to perform customized interconnection?
- To what degree should flexibility be designed into an interconnection package such that it can be scaled to different power levels, or to multiple DER units?

DER Can Interconnect in Several Places



Different voltages require different interconnection technologies

Interface Configurations Vary by DER Applications

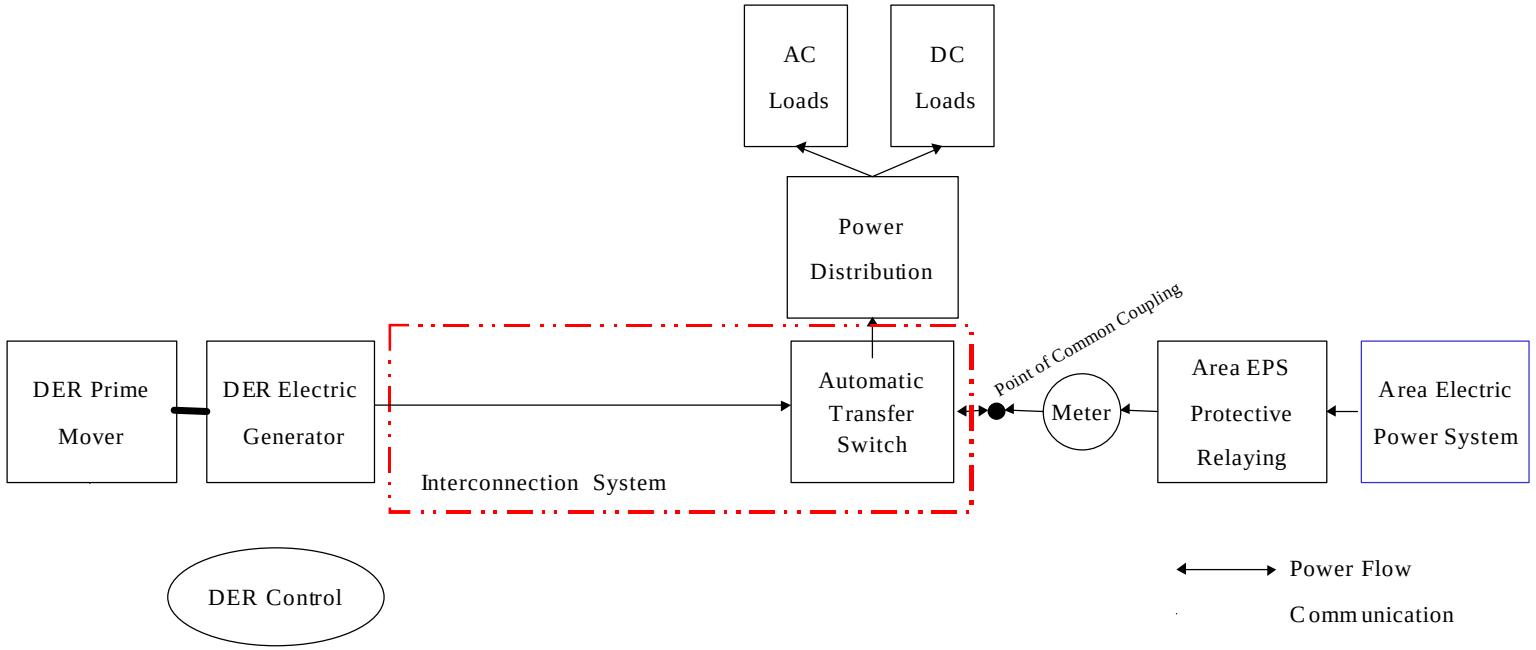
	No Interconnection	Isolated DER Operation With Automatic Transfer To Area EPS	Parallel Operation To Area EPS, No Power Export	Parallel Operation To Area EPS, Power Export To Area EPS
Baseload	✍	✍	✍	✍
Cogeneration	✍	✍	✍	✍
Peak Shaving		✍	✍	✍
Emergency/Backup		✍	✍	✍
Premium	✍		✍	✍
Remote	✍			

Different DER applications require varying interconnection complexity: most interconnection today is performed on a site and DER unit specific basis

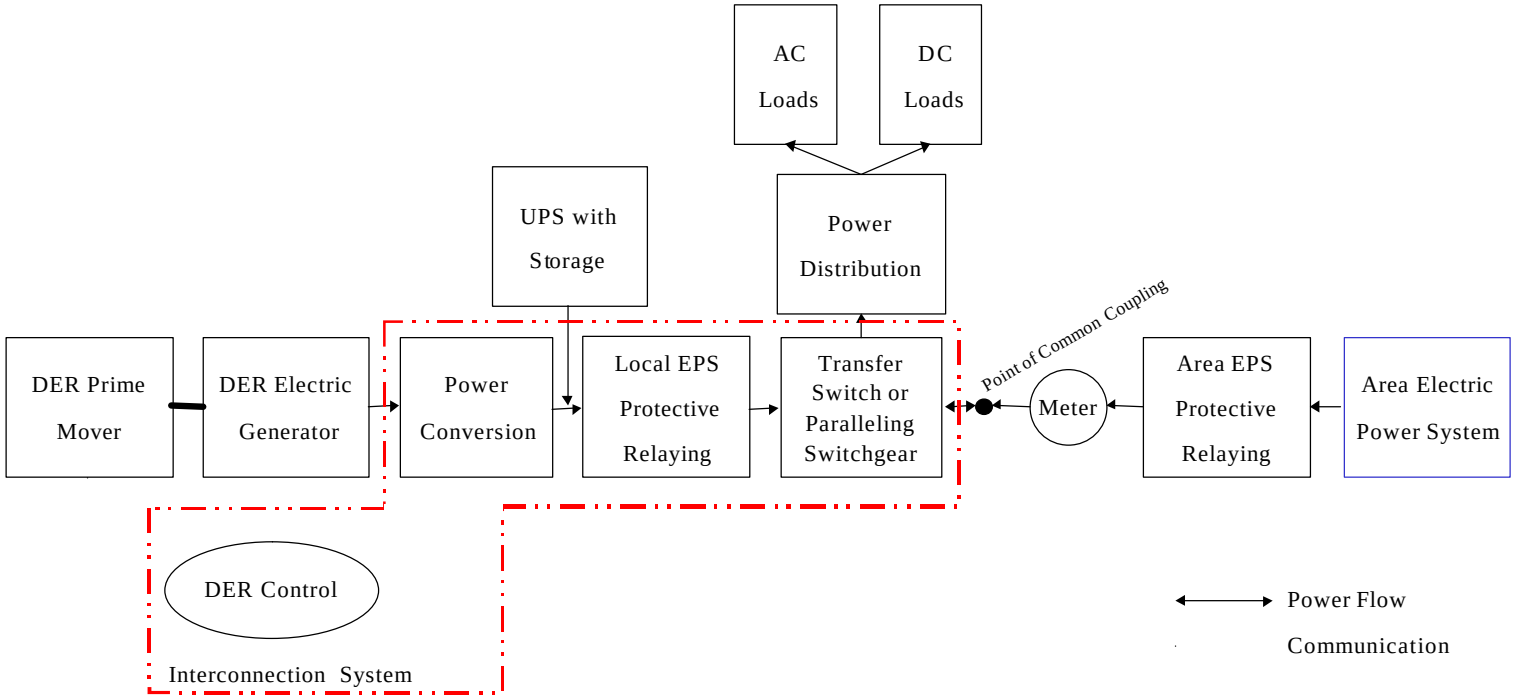
Differentiating Interconnection Systems

- Does the system use an inverter?
- Does the system have a parallel connection to the Area EPS?
- Can the system export power to the Area EPS?
- Is the system remotely dispatchable?

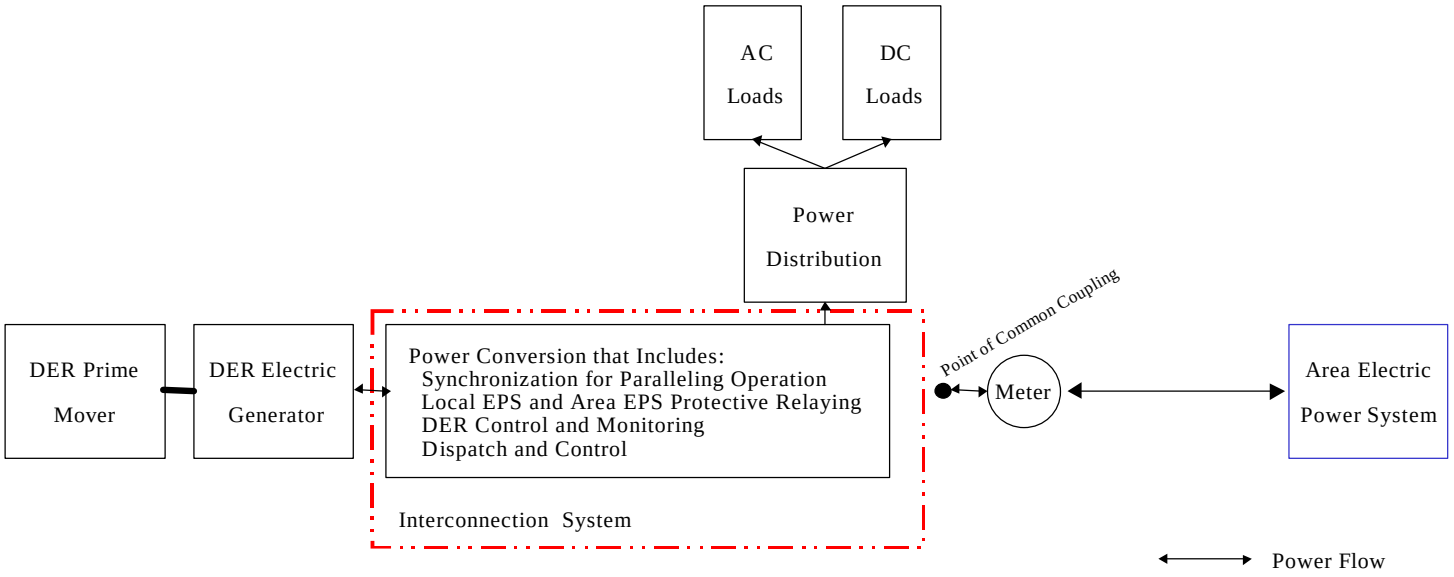
Reciprocating Engine/Combustion Turbine Used for Emergency/Backup



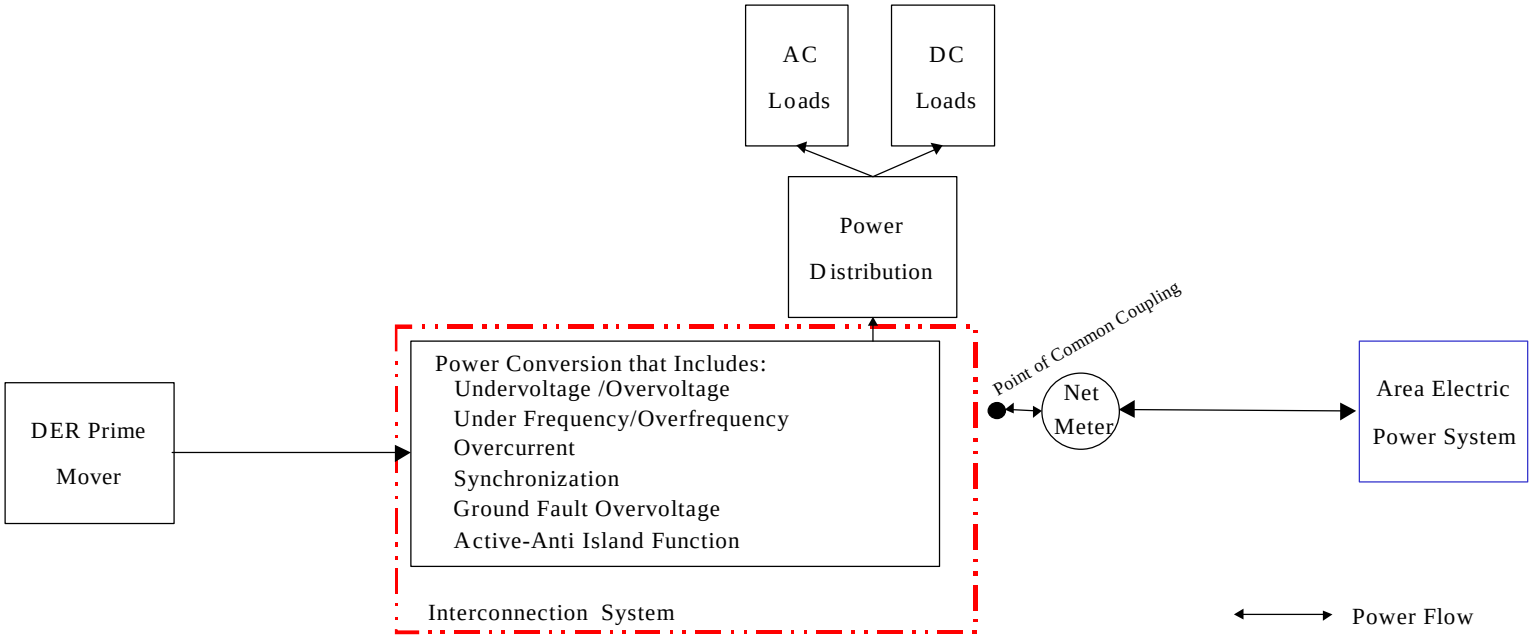
Reciprocating Engine/Combustion Turbine Used for Premium Power



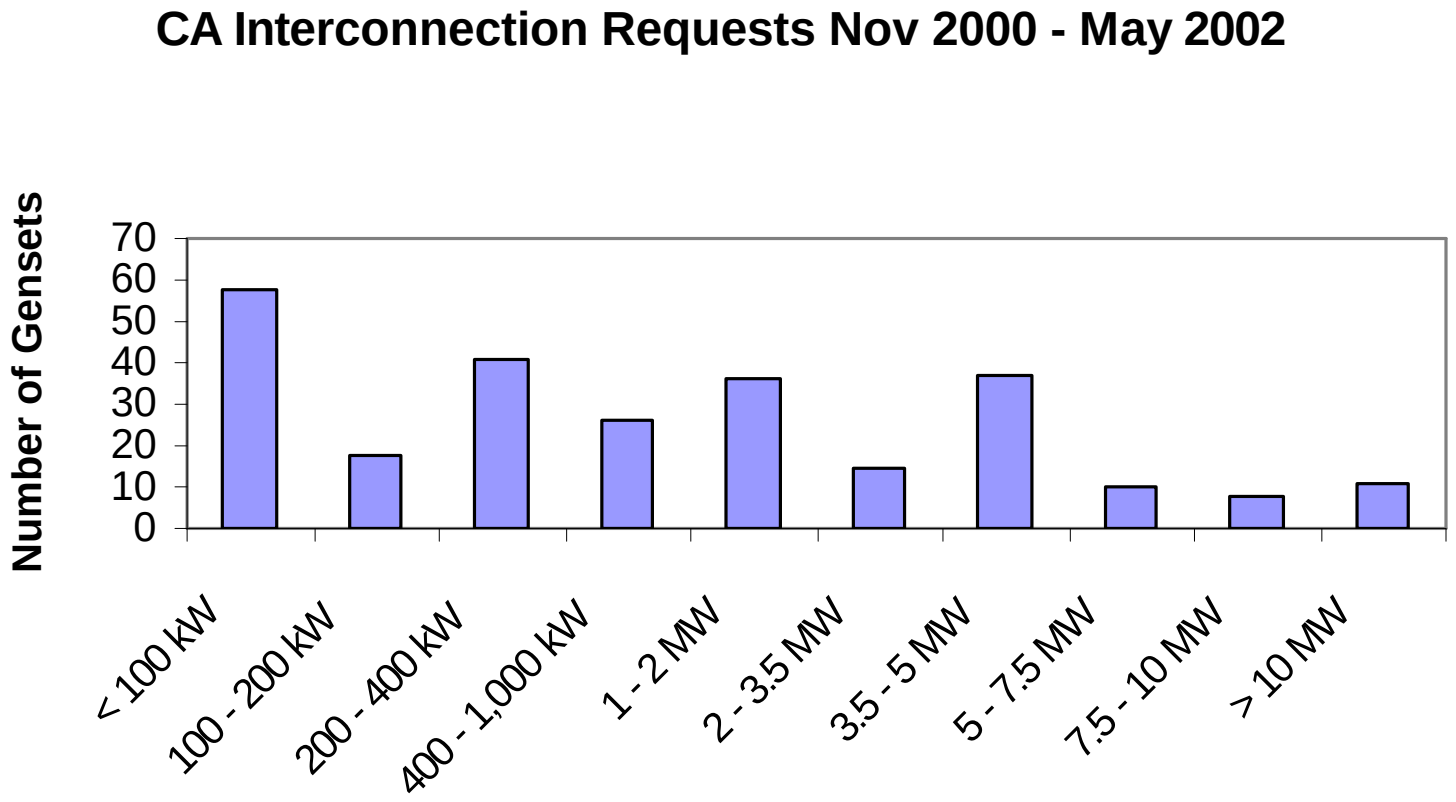
Microturbine Used for Prime Power, as a Peaking Unit, For Backup or For Power Export



Small PV System with Net Metering



Many DER Sizes are Being Interconnected



Genset Control System Components

1. Genset controls, including governor control and voltage regulation
2. Man-machine interface at the genset, control room near the genset, and remote sites
3. Communications interface to the controllers, hardware and operating system software for the control system
4. Power management software that manages the gensets in relation to the grid as well the protective relay functions
5. Monitoring and metering module

Current Interconnection Capabilities

- Exciter control system for generators
- Synchronizer to transfer power between the generators and the grid
- Automatic transfer switch control
- Import/export control
- Protective relay functions
  - Over/under frequency and voltage
  - Directional real and reactive power flow
  - Phase-to-phase current balance
- Metering or net metering
- Remote communications capabilities

These may or may not be modular components

Categories of Interconnection Equipment Product Offerings

1. Transfer switches
2. Paralleling switchgear
3. Dispatch, communication, and control
4. DER controls
5. Power conversion
6. Metering and monitoring
7. Relays and protective relaying

Most genset control system components could be and sometimes are built into an interconnection system

Many Companies Make Interconnection System Components

- **Transfer Switches:** ABB, ASCO, Capstone, Caterpillar, Cummins, Cutler-Hammer, Cyberex, Danaher, Generac, GE Zenith, Inverpower, Kohler, L-3 Communications, PDI, S&C, Siemens, Silicon Power, Thomson Technology

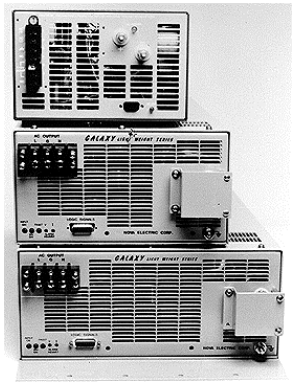
- **Paralleling Switchgear:** ABB, Alpha Power, Cummins, Cutler-Hammer, Encorp, Enercon, Generac, GE Zenith, Integrated Power, Kohler,Mitsubishi, PACS Industries, Siemens, Square D, Thomson Technology, Toshiba, ZTR Control

- **Dispatch, Communication and Control:** ABB, AeroVironment, Alpha Power, ASCO, Capstone, Caterpillar, Encorp, Enercon, GE Zenith, Hydrogenics, Invensys, Mitsubishi, Power Measurement, Siemens, Silicon Energy, Toshiba

Companies (continued)

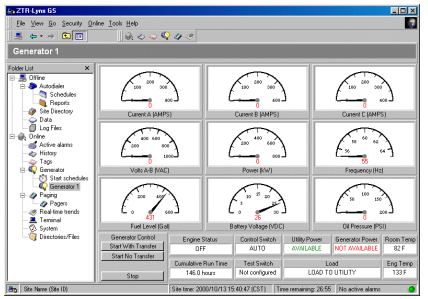
- **DER Controls:** ABB, AeroVironment, Alpha Power, ASCO, Basler, Beckwith, Capstone, Caterpillar, Cummins, Detroit Diesel, Encorp, Enercon, Generac, Hatch & Kirk, Ingersoll-Rand, Integrated Power Solutions, Invensys, Kohler, Petrotech, Solectria, Sonat Power Systems, Thomson Technology, Toshiba, Waukesha, Woodward, ZTR Control Systems

- **Power Conversion (including Inverters):** ABB, Advanced Energy, Cherokee Electronics, Exceltech, GE Zenith, Inverpower, L-3 Communications, Magnetek, Mitsubishi, Nova Electric, Philtek, S&C, Siemens, SMA America, Solectria, Solidstate Controls, Toshiba, Tumbler Technologies, Vanner, Xantrex, Woodward



Companies (continued)

- **Metering and Monitoring:** ABB, Advanced Energy, Alpha Power, Ametek Power Instruments, ASCO, Basler, Beckwith, Capstone, Caterpillar, Cutler-Hammer, Electro Industries, Encorp, Enetics, Generac, GE Zenith, Heliotronics, Hydrogenics, Invensys, L-3 Communications, Liebert, Measurlogic, Omnimetrix, PDI, Power Measurement, Reliable Power Meters, Siemens, Simpson, Square D, Thermo Westronics, Toshiba, Vanner, Woodward, ZTR Control



- **Relays and Protective Relaying:** ABB, Basler, Beckwith, Capstone, Cutler-Hammer, Encorp, GE Zenith, Schweitzer Engineering Labs, Siemens, Square D, Toshiba, ZTR Control

All companies are not designing their architecture to the same standards; not all equipment can work with other components

Products Characterized by Company and Type

Manufacturer	Contact Information	Transfer switches	Paralleling switchgear	Communication and control	DER generator control	Power conversion, Inverters	Metering and monitoring	Relays and protective relaying
ABB Automation, Inc.	www.abb.com/, www.abbus.com/papd	X	X	X	X	X	X	X
Advanced Energy Inc.	www.advancedenergy.com/					X	X	
AeroVironment Inc.	www.aerovironment.com			X	X			
Alpha Power Systems, Inc	www.alpha-power-systems.com		X	X	X		X	
Ametek Power Instruments	www.ametek.com						X	
Asco Power Technologies	www.asco.com	X		X			X	
AstroPower, Inc.	www.astropower.com							
Ballard Generation Systems	www.ballard.com							
Basler Electric Co.	www.basler.com				X		X	X
Beckwith Electric Co., Inc.	www.beckwithelectric.com				X		X	X
Capstone Turbine Corporation	www.capstoneturbine.com			X	X		X	X
Caterpillar, Inc.	www.cat.com/	X		X	X		X	
Cherokee Electronics	www.cherokeeelectronics.com					X		
Cummins Power Generation	www.cumminspowergeneration.com	X	X		X			
Cutler-Hammer	www.ch.cutler-hammer.com	X	X				X	X
Cyberex	www.cyberex.com	X						
)etroit Diesel (DaimlerChrysler)	www.detroitdiesel.com				X			
Electro Industries/ Gaugetech	www.electroind.com						X	
Elliott Energy Systems, Inc.	www.tapower.com	X	X	X	X	X	X	X
Encorp, Inc.	www.encorp.com	X	X	X	X		X	X
Enercon Engineering	www.enercon-eng.com		X	X	X			

Interconnection Product Pricing

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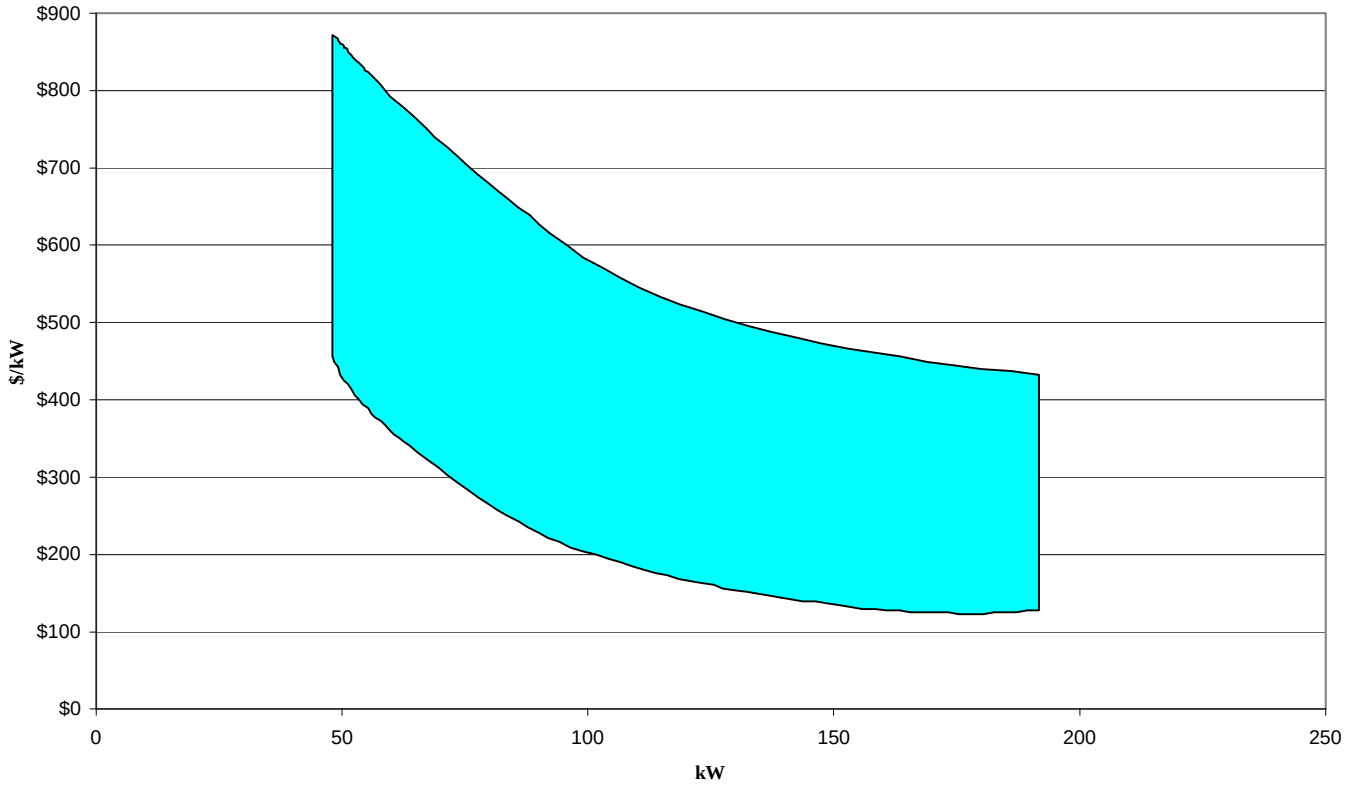
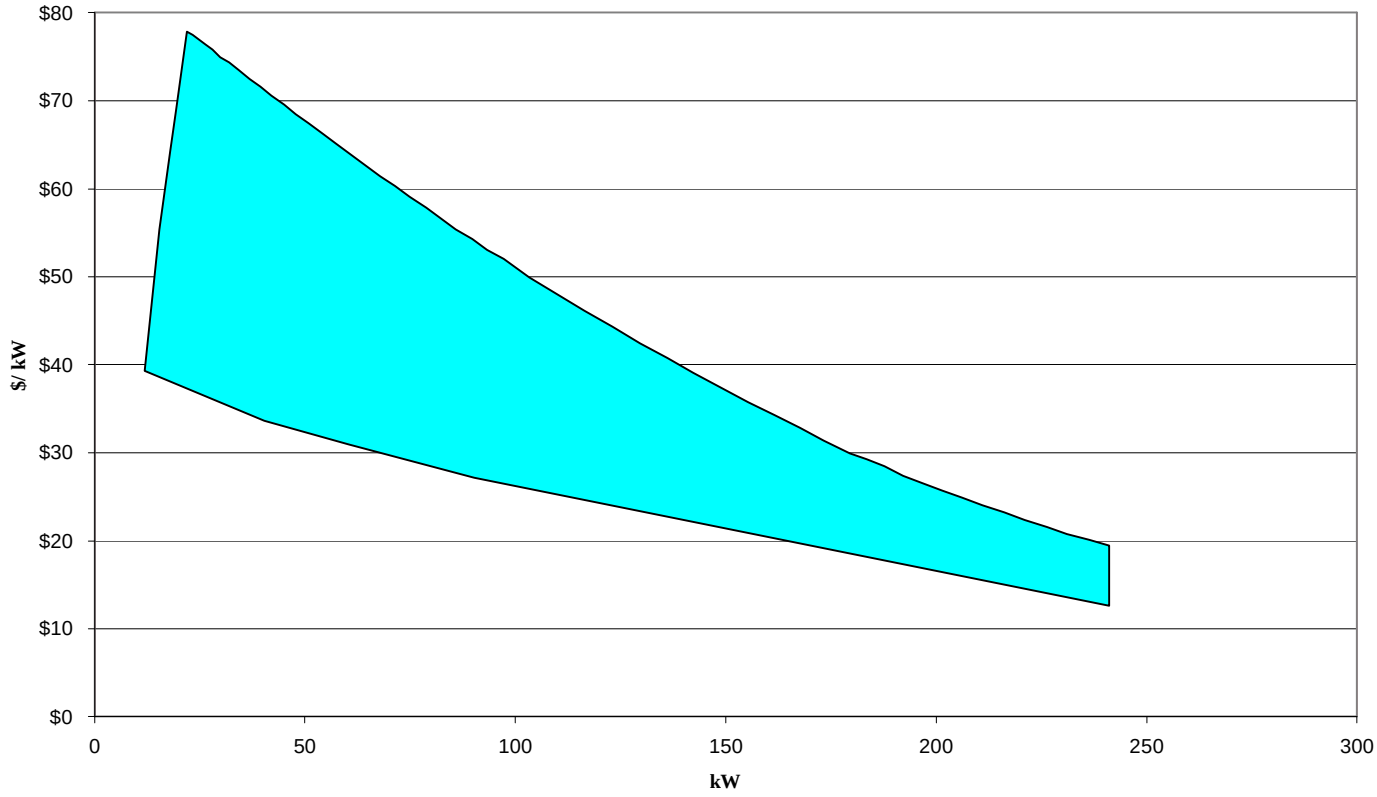
Static Transfer Switch Pricing, $/kW

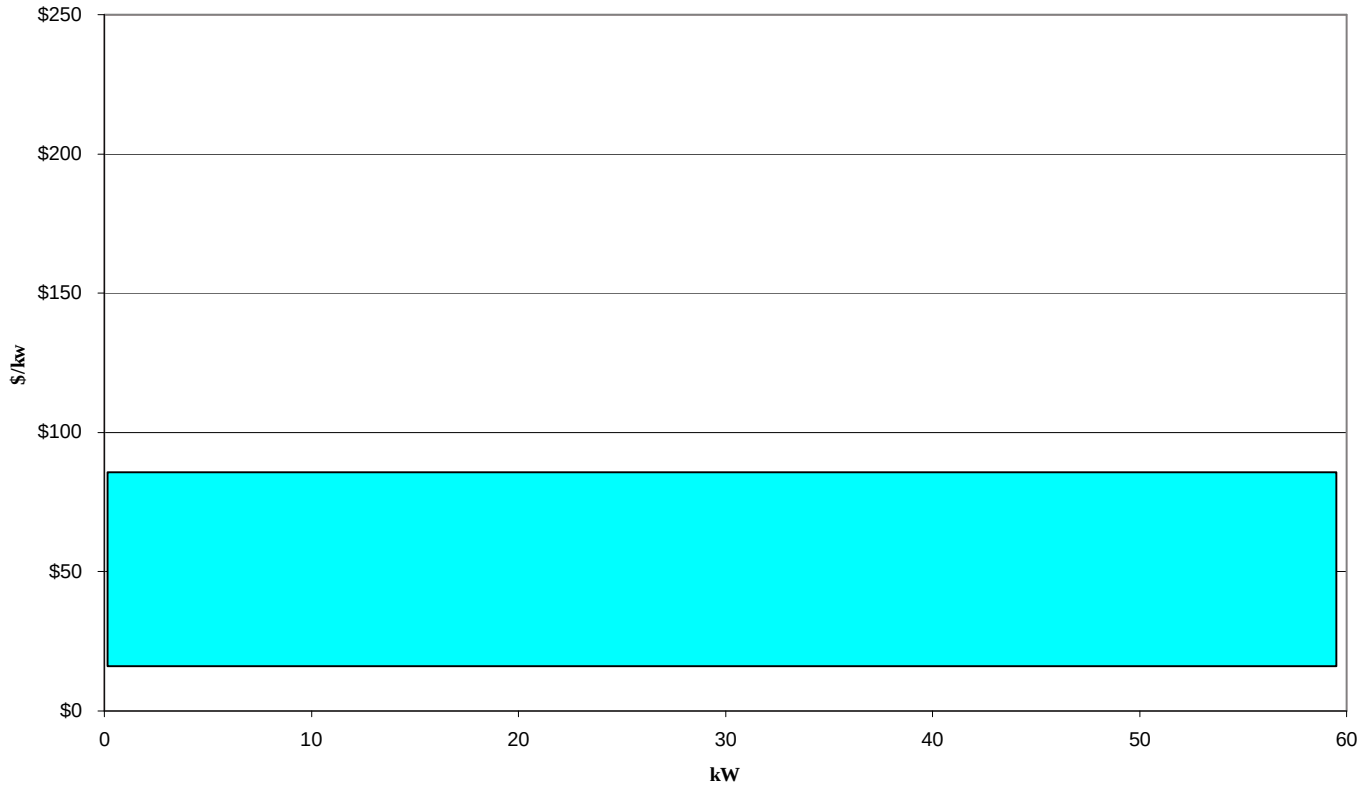


Note: Price includes a power distribution unit (PDU)

Automatic Transfer Switch Pricing, $/kW

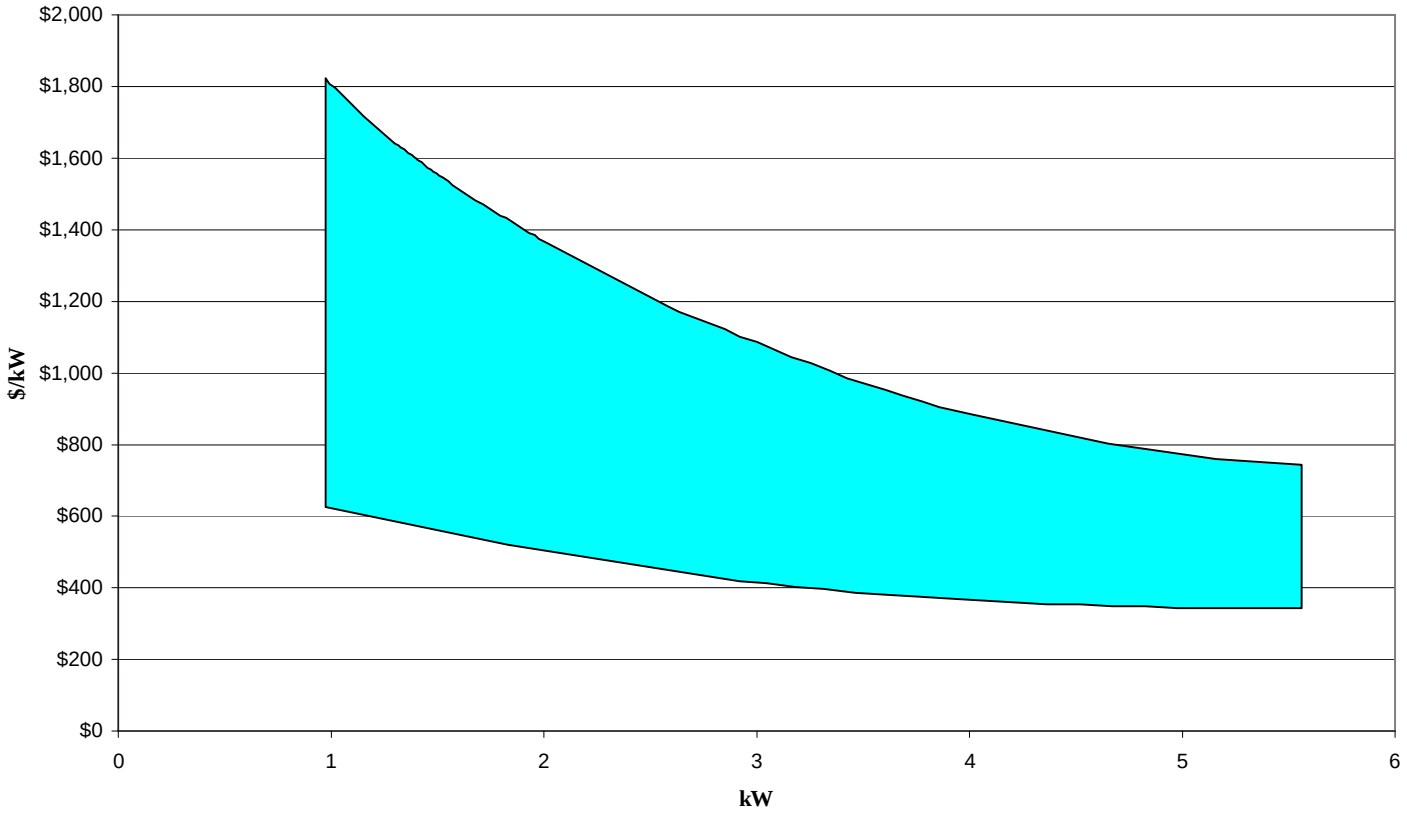


Manual Transfer Switch Pricing, $/kW



Price does not vary appreciably with kW rating

Inverter Pricing, $/kW



Inverters often work with smaller kW DER generators

Typical DER Siting Costs

- Siting costs vary greatly by project size, location, complexity and the role of outside parties

Typical Costs per kW

Cost Category	DER Units <500 kW	DER Units >500 kW
Genset capital cost	$600-1,500	$400-1,200
Engineering, permitting, installation	$200-700	$150-600
Interconnection and testing	$75-300	$25-200

- "Individual" site specific interconnection packages increase cost of equipment as well

Interconnection Codes and Standards

- Three organizations are major players in the DER interconnection codes and standards arena
  - Institute of Electrical and Electronics Engineers (IEEE)
  - National Fire Protection Association/NEC (NFPA)
  - Underwriters Laboratories (UL)
- Others also issue standards and regulations
  - International Electrotechnical Commission (IEC)
  - American National Standards Institute (ANSI)
  - American Society of Mechanical Engineers (ASME)
  - American Gas Association (AGA)
  - National Electrical Manufacturers Association (NEMA)
  - Electrical Generating Systems Association (EGSA)
  - Federal, State and Local Governments

As standards and certification methods evolve, additional RD&D may be necessary to respond to any new requirements

Key Issues Driving RD&D Needs

- Lower cost, better performance issues
- Functionality of interconnection package
- Grid vs. customer standards
- Where to include the capabilities (UIT “black box” or generator controls?)
- Interface standards between DER and interconnection package
- Issues of scaling to different power levels

RD&D Trends in Enabling Technologies

- Communications
  - “Grid-to-chip” communications
  - Monitoring vs. control
  - When needed vs. operating mode
- Controls packaging
- Increased functionality of digitally-based equipment, frequently with multi-function capability

Technical Issues Still to be Addressed

- Interconnection technology cost
- Demonstrated (certifiable and verifiable) performance
- Changing technical standards and local building codes
- Evolving role of special control systems, paralleling switchgear, and transfer switches

Much technology exists, and even as incremental technical improvements are made, most RD&D efforts are designed to improve system economics

Implementation Strategy and Outreach Options

- Public-private partnerships
- Technology roadmapping
- Testing and certification practices review
- Market information development

These create a foundation
for a robust RD&D program

RD&D Needs and Activities

- Standardize the design, engineering and installation of DER technologies
- Develop advanced communication and software platforms
- Simplify the technical and design aspects of DER interconnection
- Establish the ability to enhance grid intelligence
- Remove regulatory and institutional barriers